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Evaluation of the streaming current detector (SCD) for coagulation control

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Abstract

A streaming current detector (SCD) is an instrument for measuring the charge that exists on small, suspended particles in water. The SCD is the instrument that can be used to measure coagulated particle stability for the feedback control of coagulant dosage. This report discusses the application of SCD as an instrument for coagulation dosage control. The SCD with automatic control of coagulant dosage consistently produced acceptable water quality, even during periods of changing raw water turbidity and varying flow rates. It minimizes under and overdosing of coagulant. It requires regular cleaning and maintenance to ensure optimum operation. The SCD is no substitute for efficient water treatment management.

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Keywords: Streaming Current Detector; SCD; coagulation; potable water treatment; drinking water treatment; water treatment

1. Introduction

In most waterworks the determination of the optimum coagulant dosage is established by jar test in combination with operators' assessment. Edney and Edgar et al. (2005) indicated that this process is time consuming and in some instances unreliable. The need for a feedback control system for continuous coagulant dosage control has become necessary due to changing raw water quality and water production rate changes based on consumer demand patterns in a 24 hour plant operation cycle and increasing cost of chemicals. Coagulation is first and one of

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the most critical steps in water treatment processes and it needs to be well optimized. An efficient auto coagulant dose control system using Streaming Current Detector (SCD) technique also optimizes chemical usage.

The SCD is generally effective in situations where changes in raw water flow rates in the plant also require proportional changes to the coagulant flow rate to maintain the current coagulant dose. The SCD is also effective in adjusting coagulant dose in response to raw water flow rates, quality and coagulant used (AWWA 1988, Christopher et al. 1996).

SCDs have found widespread use in water treatment plants. The instrument is claimed to provide a number of benefits in monitoring and controlling coagulant feed rates, including Slater et al. (2003) and AWWA (1988, 1990):

- Maintain consistent high quality of final water
- Handles changes in raw water conditions
- Automate coagulant dosing
- Ensure coagulant reliability
- Record changes in water chemistry
- Reduce dosing chemical usage
- Optimize dosing chemical usage
- Prevent plant upsets due to early detection of plant malfunctions.

Automatic coagulant control is ensured mainly by streaming current detectors (SCD) which measure the residual charge on colloidal color and turbidity particles in the water. As these particles have a negative charge and the coagulant ions have a positive charge, the amount of coagulant added dictates the magnitude and sign of the net electrical charge. The system controls this net charge at a set point which has been shown by jar testing to provide close to optimum coagulation under a certain range of raw water conditions.

The aim of this study was to assess the feasibility, in the laboratory, of a SCD to control coagulation when polymeric coagulant is employed as primary coagulant. The instrument being evaluated was the 16mp Streaming Current Detector, supplied by Lechintech

1.1. Theoretical operating principle of the SCD

The SCD essentially consists of a sensor and a signal processor. A simplified diagram of the sensor is presented in Figure 1.The sensor chamber is a closed unit with an inlet and outlet for the test water sample containing the particles that flow through the unit at a rate of about 1 – 3 liters per minute. Inside the chamber is a piston that moves vertically in a reciprocating motion. The piston moves inside a cylinder with a velocity that is sinusoidal in nature. It is the motion of charged particles in the space between the piston wall and the cylinder (called the annulus) that is critical to the ion charge analyzer. Figure 2 shows the annulus, which is in the shape of a thin cylindrical shell, containing the sample fluid and particles. Also shown in Figure 2 is the position of the electrodes in the SCD sensor. Generally, these are two metal rings located in the upper and lower areas of the cylinder.

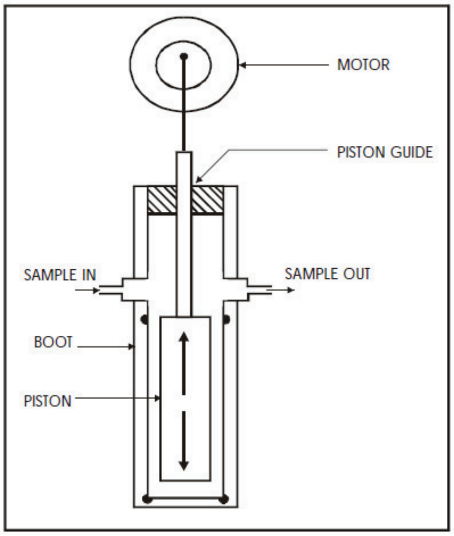


Figure 1: SCD sensor (AWWA, 1988)

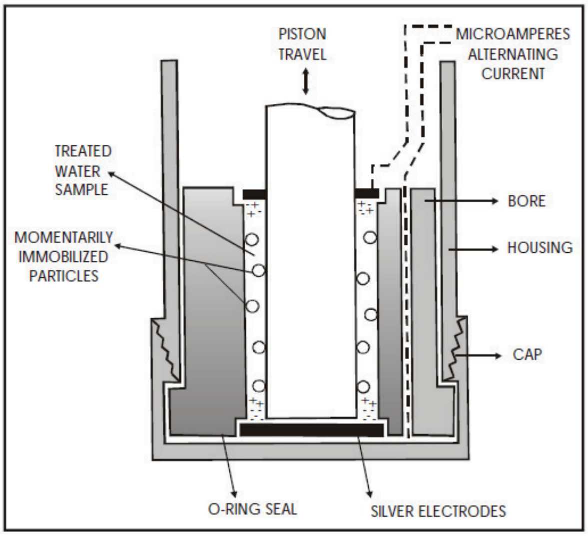


Figure 2: Sensor electrode location (AWWA, 1988)

The cylinder wall and the piston are manufactured from a special material (Teflon) that allows particles to stick on to the surface. As water flows in the annular space between the cylinder and piston, the cylinder walls and the piston become coated with particles. By their nature colloidal particles in natural raw water, are negatively charged and are said to have a negative charge density. The overall electrical charge in the water system must be neutral; therefore, the particle is surrounded by a positive charge density, called the counter ions, in water. Between the two layers of charge (negative charge close to the particles and positive further away from the particles) is the plane of shear. The motion of the piston in the cylinder causes fluid motion in the annulus of the SCD and consequently fluid shearing at the shear plane. There are two shear planes, one near the cylinder wall and the other near the piston wall. Essentially, two layers of charge move relative to each other. The movement of charge between the upper and lower electrode (Figure 2) constitute an electrical current. This current is dependent on the velocity of the fluid and the charge density. If the piston motion is constant, then the magnitude of the charge density is proportional to the magnitude of the ion charge and is determined by the amplitude (peak) height of the alternating current signal.

The current generated in the sensor is in the order of 10-12 amps. Very careful processing and amplification of this signal is necessary to avoid interferences due to electronic noise. This signal can be output to a read-out, chart recorder or a control system for chemical feed.

1.2. Application in process monitoring and control

The ion charge reading is proportional to the charge density of the particles in the water sample. The usefulness of SCD depends on the mechanism of charge neutralization, where a coagulant is added into the water to neutralize the negative charge density on the particles (coagulation). The destabilized particles adhere to adjacent particles (flocculation).

The addition of cationic coagulant to raw water, typically containing negatively charged colloids, neutralizes the charge on the colloidal particles. The neutralized colloidal particles, do not contribute to the ion charge and the net result is a relatively more positive ion charge response. Generally, the main criterion for optimum coagulant dose is the settled turbidity and the ion charge at that point corresponds to the target or set-point ion charge. Since an increase in colloidal concentration would impact on the net charge density in the sample, ion charge measurements are used to monitor and control coagulant dose. A typical application of the ion charge analyzer is shown in figure 3.

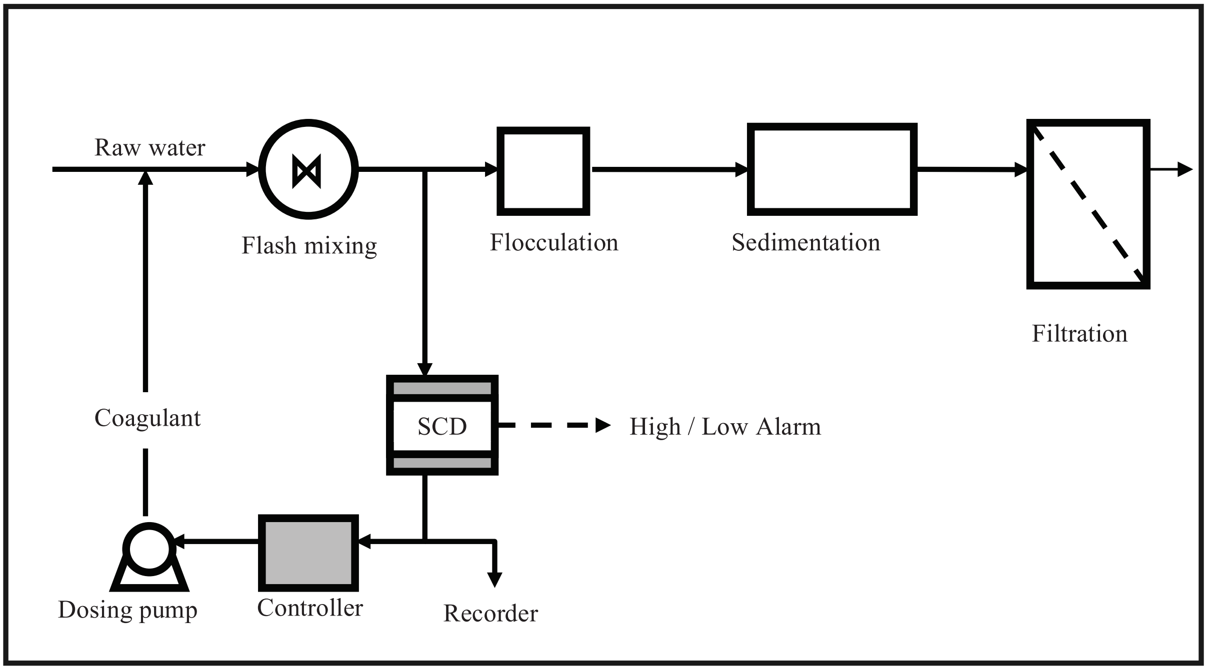
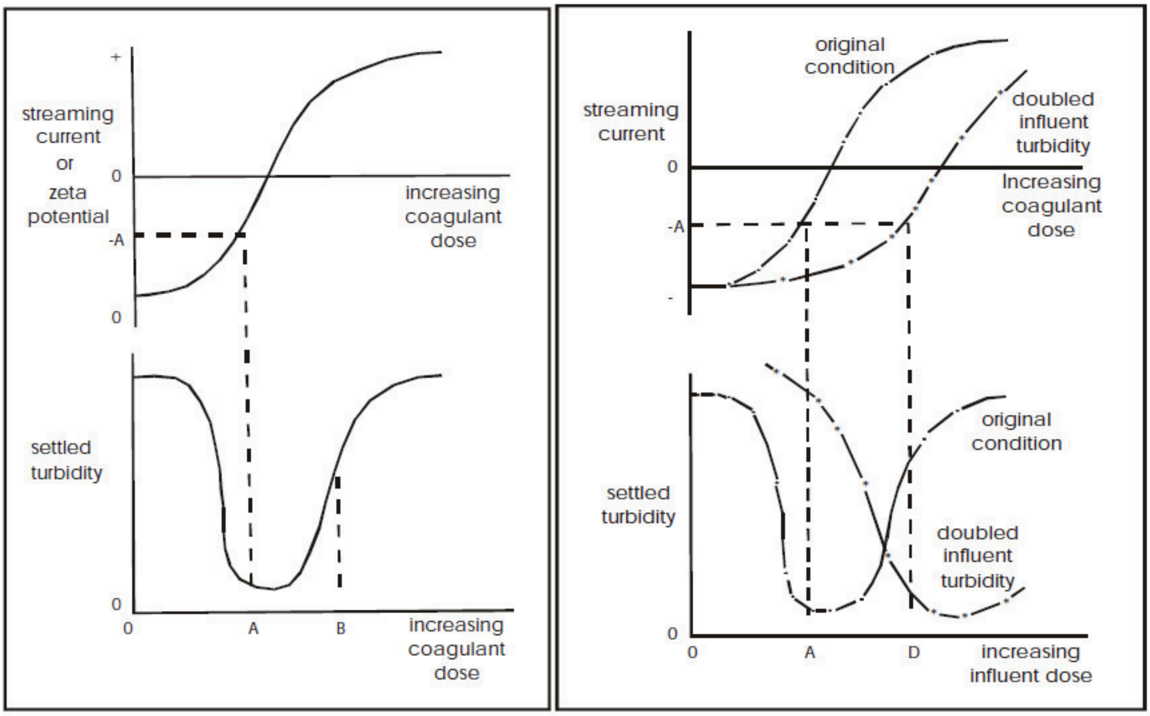


Figure 3: Application of SCD to coagulant dose control (Rajagopaul, 2002; Edney,)

The electronics of the ICA has been designed to give a negative digital output when the test sample contains an excess of negatively charged particles (typically raw water) and a positive reading when the sample contains an excess of positively charged particles (industrial effluent and process water). It has also been designed to give a large increase in positive ion charge readings for the addition of small increments (0.1mg/l) of cationic polymeric coagulants, in excess of the cationic demand of the water. A typical coagulant dose versus settled turbidity and the corresponding IC readings is presented in Figure 4(a). It can be seen that the optimum coagulant dose (A) corresponds to the streaming current reading (A1). Also from Figure 4(a), a coagulant overdose situation, indicated by "B" in the re-stabilization region, can be easily picked up by the corresponding ion charge reading. Dependence on turbidity measurements alone can be misleading in a coagulant 'under dose' or 'over dose' situation



Figures 4(a) and 4(b); Variation of settled turbidity and ion charge with coagulant dose (AWWA, 1988)

Figure 4(b) shows that the ion charge at optimum coagulant dose remains constant despite a two-fold increase in raw water turbidity. The ion charge follows a similar trend for fluctuations in raw water flows.

The optimum coagulant dose is determined from jar tests. After switching the coagulant dosing control to manual, the (jar test) recommended dosage is applied to the plant. The dosage is adjusted, using the cascade test results and settled water overflow turbidities, until the dosage is optimized. The plant is continued to operate on manual until process stability is attained, including stable reading on the SCD. The resultant SCD reading is taken as the process set point value (SP), set on the PLC /SCADA. The forward feedback control is configured to maintain the SCD set point by adjusting the coagulant dosing pump flow rate.

In a water treatment plant the SCD will be positioned downstream of the point of coagulation, after the coagulant has been completely dispersed throughout the water. An operator can adjust the coagulant dose based upon a previously determined value associated with plant performance. This point is referred to as the set point (SP).

2. Material and methods

The Vaal Dam raw water was used to conduct jar test experiments. Polymeric coagulant (SUDFLOC 3835) was employed as primary coagulant. The experiments to control the polymer dosage as primary coagulant were conducted on bench scale. Rapid mixing was performed at 200 rpm for two minutes. A sample of coagulated water was taken and streaming current was measured on the coagulated water. The SCD reading was measured at 30 second interval for the duration of 5 minutes. The average value was then recorded. Table 1 below indicates specification of SCD employed.

Table 1: Specifications of the model SCD 16mp

Parameter	**Technical data**
Range	-5ICu to +5ICu
Accuracy	Ion Charge: ± 0.1ICu Cationic demand: ± 1% Cationic
Power supply	220 VAC 50 Hz at 12VA A solid earth connection is essential
Probe	Immersible to depth of 120 mm in sample. 6 to 10 l/min sample flow rate required at 30KPa max.
SCD dimensions	Height : 320 mm Width: 160 mm Depth : 100 mm
Calibration	Two points: zero and positive span in cationic standard solution.
Measuring mode	Ion charge (ICu)
Communication interference	4 – 20mA linear output scaled -5.00 ICu to +5.00 ICu
pH range for operation	3 – 12
Conductivity range for operation	0 – 500 mS/m
Temperature	5^0C – 60^0C
Weight	4.5 kg

http://www.lechintech.com/pdf-manuals/LDT_16mp_manual.pdf. Accessed May 2013

The streaming potential is an inverse phenomenon of electro-osmosis in a capillary system, which is closely related to zeta potential and is represented by terms as pressure difference and zeta potential by Helmholtz equation (8).

$$SP= \Delta P \text{ב} D/4\pi \eta \kappa$$

Where SP is the streaming potential (unit less), ΔP the press (potential) difference, ב the electrokinetic potential, D the relative permittivity of the electrolyte, η the viscosity coefficient and κ is the specific conductivity. The SP, which can be measured using a detector, is both an absolute and relative value. The former is a theoretical value that represents the charge in the water flowing between the two electrodes; the latter is the value which is manually set after appropriate manipulation or experiments.

3. Results and discussion

3.1. Optimum concentration of calibration standard

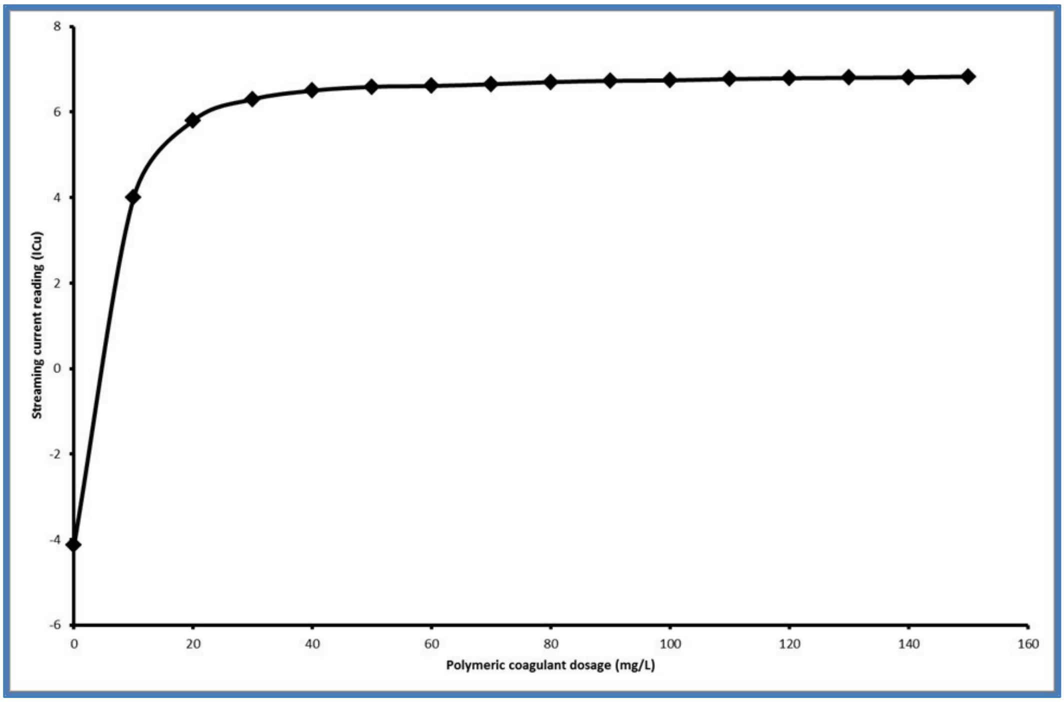


Figure 5: Variation of charge density with polymeric coagulant concentration

The critical criterion for the selection of a suitable standard concentration is that the standard concentration should be within the region where charge density is not significantly affected by polymer concentration. Figure 5 show that a polymer concentration of 100 mg/l was within the region where there is negligible change in ion charge relative a large change in polymer concentration. At the dosage of of 20 mg/L polymeric coagulant the SCD reached the saturation point. There insignificant change on the SCD reading with increased polymeric coagulant dosage.

3.2. Basic experiments: polymer dosage and streaming current.

Figure 6 illustrates the resulting SC as the concentration of cationic polymer is increased from 0 to 15 mg/ℓ experiment. The polymer is positively charged and influences the streaming current in this direction (less negative), a peak is then observed followed by a drop in SC. The streaming current reading increased with increased polymeric coagulant dosage. The results in figure 6 indicated that using SP enable direct control of the charge of the coagulated water by maintaining the charge neutralized condition in the continuous operation. Even though the polymer inter-bridging between raw water particles is also influential, the study regarding the optimum polymeric coagulant dosage reveals that coagulation is at optimal around the near “zero” of the streaming current. The optimum polymeric coagulant dosage is between 5 and 5.5 mg/L, the corresponding SC reading is between -1.5 and -0.5 ICu.

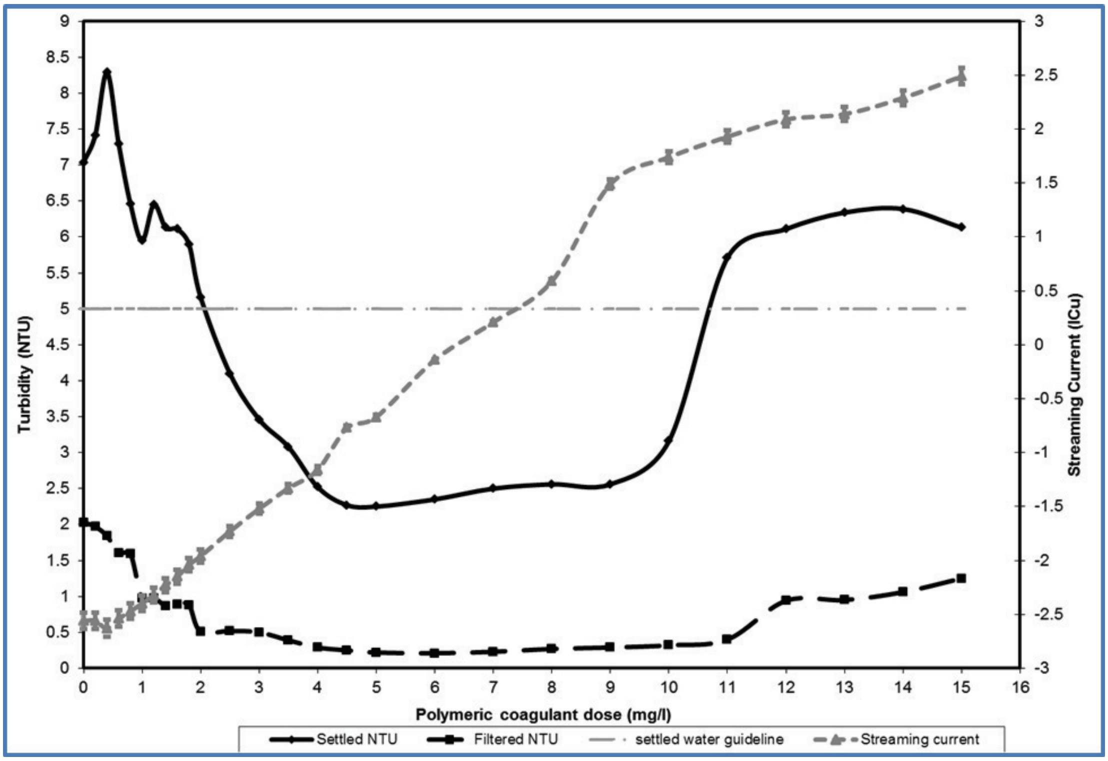


Figure 6: Streaming current variation with polymeric coagulant dosage.

3.3. Required time for complete particle destabilization

The response of the SCD coagulant dosing control loop was tested by monitoring the ICu readings of the ICA linked to the coagulant dosing pump. Figure 7 shows the ion charge measurements as a function of time during two periods. The first was a period of 'no coagulant addition' (AB) when the coagulant dosing pump was turned off, until the IC reading reached a minimum value (B). The second was a period of 'automatic coagulant control' (BC) when the coagulant pump was switched on again and automatic dosing resumed. The SCD was used to determine minimum coagulation time required at 200 rpm. Optimum polymeric dosage of 4 mg/L was added and the change in streaming current reading was monitored over the period of the time. From figure 7 complete particle destabilization was achieve within 4 minutes.

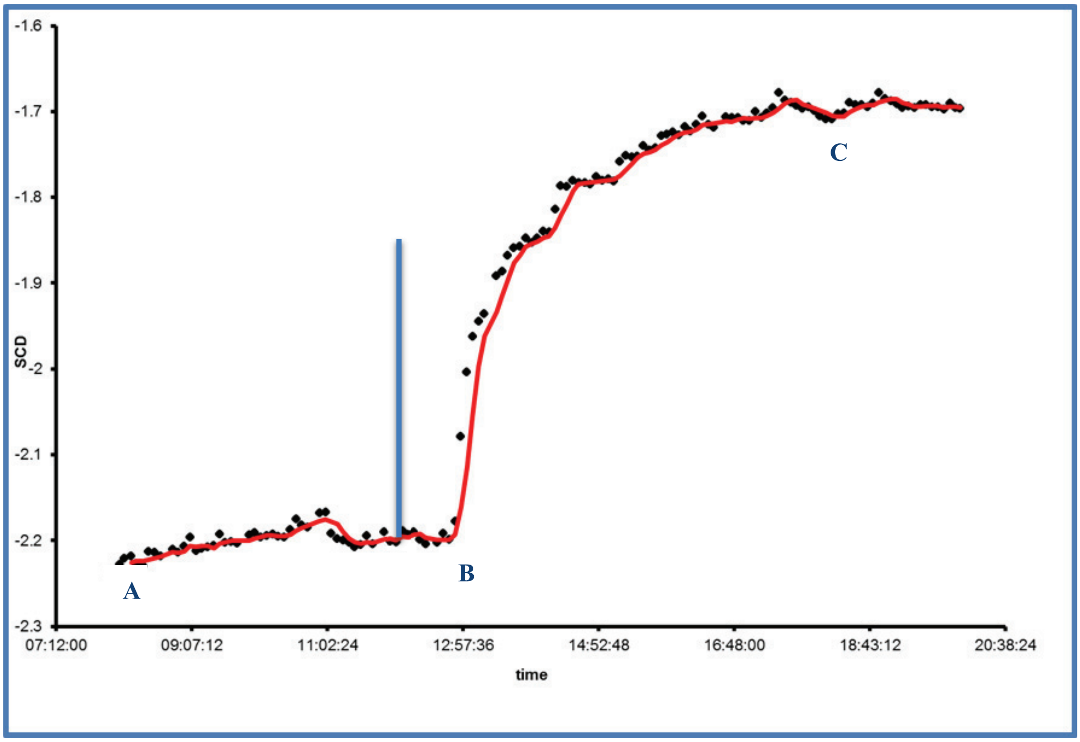


Figure 7: Streaming current detector reading (ICu) at a dosage of 4 mg/L polymeric coagulant dosage

It can be seen from Figure 7, that the ion charge set point value (-1.7) is reached after about 4 minutes from the onset of automatic coagulant dosing. The response time is a function of the PID configuration and the closeness of the initial IC reading to the set point. In general the results indicate that the SCD provides a good measure of coagulant dosing control.

4. Conclusions

- This study reports the results of the on-line control of polymeric coagulant dosage at rapid mixing step in water treatment. The results show that the SCD reading increases as the polymeric coagulant dosage increases. The supplier recommended cationic polymer concentration for an SCD calibration standard of 100 mg/l was found suitable for SCD calibration purposes
- The streaming current reading of the coagulated water at optimum coagulant dose was not significantly affected by raw water turbidity.
- Indications are that the SCD automatic control coagulant dosing has potential for operation optimization, effective and reliable.
- Comparison study of two different SCD to be conducted to determine if there are intrinsic differences from one SCD to another.

- Consideration should be given to other methods for sensor cleaning. The available methods are ultrasonic and chemical. The ultrasonic technique should be investigated.

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